THE HUMAN MACHINE

HOW YOUR BODY FUNCTIONS

BY

W. H. HOWELL, M.D.

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INTRODUCTION

People as a rule prize health only after it has been lost. We usually take little interest in and no care of our bodies until some disarrangement sends us to an expert for advice and repair.

Physicians have realized for many years that a knowledge of the healthy human body is essential if they are to restore to health the diseased body. For this reason every student of medicine spends much of his first year in studying the normal functions of the intricate human machine.

Early in this century leaders in the medical profession realized that others than physicians had a part to play in promoting health and preventing disease. Efforts to prevent disease among infants, to combat tuberculosis, to prevent the water-borne diseases, and to conserve health in other lines brought sanitarians, nurses, social-welfare workers, and others into the army fighting to conserve health. It has thus come about that there are great numbers of people who have given little study to the healthy human body who are actively engaged in some form of public-health work. These persons could certainly use their efforts more intelligently if they knew more about the working of the living machines they are trying to regulate.

It was later realized that their labor would be more effective if the persons who were to be aided also knew something of their own bodies so that they could cooperate intelligently with their advisers. The driver of a motor car who knows nothing about its mechanism except to turn on the power and direct

the car's course may for a time use it with pleasure and profit, or if it breaks down have it repaired, but the life of the car would be greater and its smoothness of operation improved if the driver knew its construction and the first symptoms of bad adjustment or breakdown. Our bodies have wonderful powers of adapting themselves to hard usage, but they also break down in time if they are abused.

Impressed with the need of giving to every one who was interested in this vitally important knowledge about themselves an authoritative account, the National Health Council sought for one who both knew the facts and could present them so as to instruct and interest the readers. Those who are acquainted with the physiologists in this country know how fortunate it was that Dr. Howell could respond to the call. A life devoted almost equally to research, teaching, and writing singularly fits him to present in a clear, authoritative, and absorbing manner an account of the functions of our human body which is the most wonderful of all machines. Those who are so fortunate as to read this book will realize that Dr. Howell has met all anticipations.

William H. Park, M.D., LL.D.,
President, American Public
Health Association.

New York, *February,* 1924.

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THE HUMAN MACHINE

CHAPTER I

FOREWORD

THE HUMAN body, or for the matter of that the body of any animal, is a wonderful machine, no other adjective fits the case quite so well. It is wonderful in its complexity and the perfection of its performance, but above all in its power of adjusting or adapting itself to the changing conditions to which it is exposed. It is true that in some cases it breaks down. Sometimes our ever-present enemies, the disease germs, get the better of it, throw a monkey-wrench into the machinery, so to speak; sometimes by unhygienic methods of living we more or less deliberately put an organ or two out of gear, and sometimes an individual is unfortunate enough to come into this world with inherited defects which hamper the normal working of his body mechanisms.

Under such circumstances the awesome intricacy of the interlocking mechanisms is borne in upon us quite forcibly and we become duly impressed, disagreeably impressed in fact, with the delicacy with which it is adjusted and the necessity that all parts shall be in good working order. Like Stevenson, we may even go so far as to think that the whole combination is a "mere bagful of petards," any one of which is liable to go off at any moment and wreck the entire economy. But in the great majority of cases the machine runs astonishingly well, and it is to be remembered that it is a self-repairing, self-adjusting, and self-perpetuating machine. All the

wear and tear and destruction that goes on in each tissue is completely replaced by new living material cunningly manufactured in a variety of forms out of dead food; all of the many adjustments to the stresses of life are carried out without extraneous assistance by a perfectly organized internal system of communications between different parts, and under ordinary conditions it not only goes on working well day and night, year in and year out, but it buds off at times, under suitable combinations of circumstances, certain little machines that grow up into large complete mechanisms like itself.

In the long run the wonder of the human machine rests upon the fact that it is composed of living matter. It is an orderly union or aggregation of uncountable numbers of minute organisms or cells, each more or less a little independent sovereignty and each exhibiting all those remarkable properties that distinguish living from dead matter. The vast communities of cells that go to form the body are closely interrelated and organized to form a complex whole that acts as a unit, and yet each individual cell has a certain life and range of activities of its own. The prosperity of the whole community depends on the integrity of the constituent cells, and on the other hand the individual units or cells can not exist when cut off from their normal habitat and connections.

It is only in recent years that we have come to recognize how very sensitive these cells are in the matter of their environment. It has long been known that they are, as a French physiologist puts it, aquatic organisms. We as individuals live in the air, but the cells of which we are composed all live immersed in the liquids of the body and if exposed to air would dry up and die, as in fact occurs constantly with those of them that lie on the surface of the body

in immediate contact with the air, the external cells of the skin. Not only must they have a liquid environment to live in, but that environment must have a very special composition. For example, it must have a certain number of inorganic salts in it in a definite concentration which can not vary a great deal. There must be salts of sodium, potassium, and calcium, and probably other elements such as magnesium, and these must exist in a certain relation to each other. If any marked variation occurs the cell will die.

Physiologists suppose that this particular composition of the fluid surrounding the cells harks back to that distant time when life first appeared on this earth, for in all probability it made its start in the waters of the sea, and tho in the course of ages the minute cells that lived free in the sea water gave rise to complex forms, and some of these in turn learned to live on the land, yet the internal liquids of the body, the blood and lymph, in which the cells live, still show a relation in their composition to that of the mother ocean. These liquids of the body moreover must have just the proper reaction. They must not be distinctly acid nor very alkaline, nor in fact neutral, but must be just a little alkaline. If there is much variation in this respect the cells can not exist. There is a great opportunity for changes to occur that might be fatal. The chemical processes in the body are constantly forming acids which if not removed or neutralized would destroy the life of the cells, and we are constantly taking into our body in our foods substances which tend to alter the reaction of the body liquids.

The newer developments in physiology have brought to light the self-regulating mechanisms in the body which are constantly in play to maintain the reaction of these liquids within the narrow

limits that are normal. It is an essential feature of the body's activity that was not known to the previous generation, and the discovery of its existence and importance should warn us that there are doubtless other self-regulating mechanisms in this complicated organism of ours of which we are as yet in ignorance.

There is still another feature of the internal environment that is worth a word of mention as it emphasizes very well the highly specialized conditions under which the cells live. In the oxidation processes of the body carbonic acid is constantly formed and the liquids, therefore, always contain a small amount of this material in solution; they are carbonated to a certain extent. If the carbonic acid is present in large concentration it is injurious or fatal, but on the other hand if it is entirely removed the result is also disastrous. There is a certain concentration that is normal and the circulation of the blood and the act of respiration must be so regulated as to preserve automatically this degree of saturation with carbonic acid.

Then there is the temperature question. As every one knows we are warm-blooded animals. The average temperature of the body is 98.5° Fahrenheit. The cells of the body, or most of them, are not able to live if the temperature rises much above this point or falls much below, and it goes without saying that there must be regulatory processes in play to maintain this relatively high temperature and to keep it fairly constant under all the changing conditions to which the body is subjected. The life of the cells at this high temperature is vastly more efficient than it would be at a lower temperature, that of the surrounding air for instance. The ability of the organism to maintain a high and constant temperature has been one of the important factors in the evolution of the higher forms of life; but this advantage

is attained at the expense of another complication in the machinery of the body, the development of a temperature-regulating mechanism which under ordinary conditions works so remarkably well, but which at times gets out of order, with the production of fever.

Considerations of this kind help to give us an understanding of the great complexity of the human machine. It contains a great number of these self-regulating devices which must work very smoothly to keep the body in normal condition. All the resources of science are needed to enable us to discover and understand these mechanisms. Progress is being made constantly. When we compare what we know with the knowledge of the ancients or, indeed, with that of the preceding generation we may well feel some pride and satisfaction. But on the other hand those who are best acquainted with the facts realize most keenly how much remains unknown. We have every reason to believe that the present methods of scientific research, or modifications and improvements of these methods that will come with experience, are adequate to unfold all these mysteries eventually—but it is no easy task and no work for amateurs. The men to win this knowledge for us must be trained and skilful workers, and everywhere throughout the civilized world institutions of learning attempt to make opportunities for properly trained men to carry on such researches, knowing well that every new fact learned helps us that much to gain an intelligent control over the processes of life, to readjust mechanisms that are out of order, and above all to protect them from going wrong. Curative medicine and preventive medicine and, in the long run, an adequate hygiene are all feasible things to strive for. In what follows an attempt is made to present some of the main

facts regarding the mechanisms of the body in a brief and simple form without the use of the many technical terms which professional workers in these subjects must use when discussing such matters among themselves.

CHAPTER II

FOOD AND THE MECHANISM OF DIGESTION

Function of Food

THE ENGINES of life must be supplied constantly with food for two main reasons, first to furnish material for the repair of the tissues, or in the case of the young animals, for growth as well as repair, and in the second place to furnish a source of energy. Like all other engines the body is a transformer of energy. It is constantly producing heat, and much work in a mechanical sense is done by it both externally and internally by means of the contraction of muscles. The ultimate source of this energy is in the food we take in. In the food it exists in the form of the so-called chemical energy which holds the atoms together, and the various processes which the foods undergo in the body liberate a part of this energy in the form of work, heat, etc. If material is taken into the mouth which the processes of the body can not attack so as to liberate a part, at least, of its energy, then such a substance does not constitute a food.

Composition of Food

By experience we have learned what materials are useful to us as foods. They exist in great variety, but scientific work has demonstrated that all of our numerous foods consist of a few fundamental substances combined in different proportions. We speak of these underlying substances as the

foodstuffs; they consist of proteins of different varieties, fats of various kinds, and carbohydrates, that is, the starches and sugars. These three substances plus water and mineral salts constitute the basis of all of our foods. Investigation in recent years has shown that to these five important substances we must add a group of bodies known as vitamins.

The vitamins are bodies of an unknown nature which exist in our various foods in small quantities by weight, but are essential in some way to normal nutrition. There are three or four or more of these vitamins. Since their chemical nature is unknown they are designated provisionally by the letters of the alphabet, as vitamin A, vitamin B, vitamin C, and so on. Each has some important and essential reaction of its own in nutrition, and if absent or present in insufficient quantity nutrition is imperfect and a diseased condition, known as a deficiency-disease, ensues. Thus if the diet is deficient in vitamin C, scurvy results. It has long been known that a diet lacking in fresh vegetables or meat induces scurvy, and it was discovered many years ago that this condition may be obviated, or cured if it exists, by the addition of such a thing as lemon-juice or orange-juice to the diet. Since there are no chemical tests by means of which these important constituents may be recognized in the foods, physiologists have been forced to determine their presence by feeding experiments on the lower animals. Diets in which one or more of the vitamins are lacking will cause sooner or later a deficiency-disease of one kind or another. By means of such experiments we are accumulating knowledge in regard to the amount of these substances present in our various foods and also in regard to the effects of the processes of cooking and drying upon their activity.

Nutrition

The practical object held in view by the physiologists in making these and similar nutrition experiments on the lower animals is to determine what constitutes a well-balanced diet, that is to say a diet which will furnish adequate material for growth and for the maintenance of the body in a perfectly normal condition. Such a diet must contain enough water for the water needs of the body, the proper inorganic salts for the maintenance of the normal composition of the liquids of the body, the right amounts of proteins, fats, and carbohydrates to furnish energy and building material to the tissues, and adequate amounts of the vitamins to ensure a normal process of nutrition. The accumulated experience of mankind has given us an instinctive knowledge of what to eat and how much to eat, and our bodily appetites on the whole constitute a safe guide when abundance of food permits entire freedom of selection. But when economic or other circumstances limit our choice serious conditions of malnutrition often ensue, and knowledge of what is indispensable for an adequate diet is essential to meet such conditions. Research work, most of it carried out in laboratories upon the lower animals, is gradually supplying this knowledge. While this knowledge to-day is by no means complete, we do have a much more complete understanding of the matter than was possessed by even our immediate ancestors.

In the nutrition of infants, invalids, poverty-stricken communities, collections of individuals such as are found in institutions, armies, etc., physiological science is utilized to select a diet that shall be adequate to the conditions existing, so as to maintain nutrition at a normal standard. It goes without

saying that knowledge of this kind can not be acquired rapidly; it must be built up slowly in the future as has been the case in the past on the results of the laborious experiments of scientific investigations, but there can be no doubt that in civilized countries where such investigations are encouraged our knowledge will increase steadily year by year. It must of necessity keep pace with developments in the manufacture of food materials, for there is always a danger that the substitution of manufactured products for natural foods may result in some detriment to the consumers. For the sake of national vitality and welfare it is desirable that the physiological value of artificial products shall be controlled by adequate physiological tests.

The Alimentary Canal

But assuming that proper food is supplied to the body in a well-balanced diet let us consider briefly the machinery employed to prepare this food so that the tissues may utilize it. If the solid or liquid food that we take into our stomachs were offered to the tissue cells in the form in which it is ingested it would do them no good, the tissue cells could not feed upon it. The proteins, fats, and carbohydrates mu t all be changed or modified to make them usable in nutrition and this duty is discharged by the alimentary canal and its appendages, the digestive glands. The alimentary canal, as its name indicates, is a tube about thirty feet long stretching from the mouth to the anus. Food goes in at one end and from the other the feces are evacuated. This tube is muscular throughout and by the contractions of the muscles the food is moved along at different rapidities in different parts, and meanwhile it undergoes digestion and absorption. The feces eliminated from the rectum consists in part of any indigestible

or undigested material that may have been eaten, but in part also of cellular débris from the walls of the canal and of remnants of the digestive secretions.

In considering the activity of the alimentary canal it is evident that there are three principal mechanisms to study; namely, the muscular movements which carry the food along in an orderly, one might almost say a purposeful manner; secondly the formation and mode of action of the digestive juices, and thirdly the mechanism by which the products of digestion are absorbed into the blood and distributed to the tissues. Each one of these acts has been subjected to very careful study through observations and experiments, and while much is known about them it stands to reason that there is much left to be found out and each will remain an object of study as long as medical science continues to flourish.

The Itinerary of Our Food

So far as the muscular mechanism that propels the food along is concerned the facts known can be stated in a few words. We begin by chewing the food in the mouth and this part of the process is entirely voluntary. Then it is gathered on the back of the tongue and swallowed. The swallowing act shoots the food very rapidly into and through the esophagus, if as is usually the case the chewed mass has a liquid consistency. The bolus in fact is shot from mouth to stomach by a sort of pop-gun action owing to a sudden contraction of the muscles of the floor of the mouth which causes a rise of pressure in the mouth and drives the food downward. It arrives at the stomach within a second after the swallowing act is made. It is a very complicated act to the physiologists for a number of muscles enter into play, but the end result is simple. From

the end of the esophagus it is squeezed into the stomach more gradually by a contraction of the muscles of its walls.

The Stomach

The stomach, as every one knows, is a dilated part of the alimentary canal, a muscular bag whose internal surface is lined with small glands that make the gastric juice. We load this stomach up by repeated swallows until the meal is finished. As soon as food gets into it the secretion of gastric juice begins and also the movements of the stomach. These latter are extremely interesting. A slow, steady contraction at the left end tends to push the food over toward the right side where the stomach passes into the intestine, but free communication between the stomach and intestine is closed by a firm contraction of a circular ring of muscle. We speak of the opening between stomach and intestine as the *pylorus,* which means gatekeeper. The food is imprisoned in the stomach between this orifice and the opening of the esophagus, which is also tightly closed during digestion. At the right end near the pylorus the muscular coat is especially strong and while food is in the stomach this part of its muscle exhibits a series of running contractions which occur at intervals of about 20 seconds. Each contraction forces the contents of the stomach up against the pyloric orifice. As digestion proceeds the food becomes softened and liquefied by the action of the gastric juice, and from time to time as this liquid material is pushed against the pylorus the latter relaxes and a portion of the stomach contents is spurted into the intestine. This process goes on for several (2 to 4) hours until finally the stomach is emptied. It will be seen, therefore, that the

stomach discharges itself into the intestine by a series of spurts, or looked at from the standpoint of the intestine this latter portion of the canal receives a number of separate charges of material from the stomach. Each charge as it passes out of the stomach is started upon its travels through the intestine, so that by the time the stomach has emptied itself we can imagine a series of separate charges or short columns of food scattered along the length of the intestine, each being moved along and acted upon as a separate unit.

It is easy to understand that these movements of the stomach are of an orderly kind. They proceed as tho they were controlled by some sort of an innate intelligent spirit, and this is in fact the way in which such acts in the body were explained by the older physiologists. We now speak of them as coordinated movements. There is a nervous and muscular machinery in the stomach which if played upon by the proper stimuli can be counted upon to act always in the same way, and physiologists have arrived at a fairly satisfactory understanding of how this machinery is arranged and of the special stimuli that set it into motion. If the pyloric orifice, for example, failed to act properly, if it remained closed all the time, the food would be retained in the stomach abnormally long and indigestion would follow with resulting pains, nausea, etc. The machine has got to act just right so that the food may not stay too long in the stomach and may be delivered to the intestine in the proper condition. With healthy people it does act just right with astonishing regularity and success, but as we all know disease and unhygienic habits of eating may upset the mechanism and cause much discomfort and unhappiness to the individual concerned.

The Intestines

We divide the intestine into two portions, the small and the large, named in accordance with a difference in diameter of the tubing. The small intestine is about 22 feet long and is coiled up in a neat way in the abdomen; the large intestine is only about 4½ feet long and at its lower end opens to the exterior through the rectum and anus. The passage from one to the other is guarded by a special ring of muscle like that at the pylorus, and during digestion this ring is opened and closed in a regular way so that the contents of the small intestine are passed into the large intestine in a series of separate charges.

The progress of the food along the small intestine is peculiar. On account of the way it is received from the stomach in separate charges, as explained above, the food lies along the small intestine in a broken series of short columns of liquid material. Where each one of these columns lies the intestinal musculature is stimulated to make a series of rhythmic contractions like the beating of a heart, and the result of these contractions upon the stationary column of liquid is to divide it up, or one might say churn it up, so as to mix it thoroughly with the intestinal secretions and to bring constantly new portions of the material into contact with the walls of the intestine through which the finished products of digestion are being absorbed. After this kind of activity has gone on for some time, several seconds or longer, there suddenly appears a different kind of contraction, a running wave of contractions or, as it is called, a peristaltic contraction which rushes the whole column along for a distance of say 3 inches, when the column again comes to rest and the churning movements begin in the new location, to

be followed soon by another running wave, and so on. In this way each of the separate short columns of food along the intestine is churned and moved forward alternately and finally discharged into the large intestine, minus whatever products of digestion have been absorbed from it during its transit, and plus whatever liquid secretions may have been added to it. Here again is a very orderly and purposeful kind of movement, carried out wholly unknown to our consciousness by a definite mechanism of muscle and nerve which is set into action by stimuli furnished by the food itself. All the essential mechanism is self-contained. The intestines, and the stomach too, if taken out of the body and supplied with blood, proper temperature, and other necessary normal conditions would react in the same way to the same stimuli.

In the large intestine the kind of movement is quite different. Altho it has now only a few feet to go, about eight hours are required for the passage. The peculiarities of these movements are not so well known as in the small intestine, but in general it may be said that at certain long intervals a slow running contraction occurs which shifts the material from one section to a succeeding one. In this long stay in the large intestine the liquid contents undergo solidification, owing to absorption of water, until the consistency of the feces is reached. This latter material as it accumulates at the lower end of the bowel gives rise by pressure to a conscious sensation, a desire to defecate, that leads us to evacuate the bowels by an act partly voluntary and partly involuntary. It is rather interesting to note that when this passage of the food along the alimentary canal is entirely normal, it causes in us no conscious sensation of any kind from the time it leaves the mouth until it reaches the rectum. The mouth cavity and

the rectal cavity are provided with tactile nerves which are stimulated by the pressure of the food, but along the greater part of the canal such nerves are lacking so that all the various things that happen to the food make no impression, fortunately, upon our consciousness. If anything goes wrong, if there is an obstruction for example, and the tube becomes unduly distended, and the contractions as a consequence unduly strong, then we may suffer painful sensations, possibly of a most violent character.

How the Food is Changed and Used

During its slow and irregular progress along the alimentary canal the food undergoes many changes, the total result of which is that most, in some foods practically all, of the usable material is extracted and absorbed into the blood altho in a different form. The chemical changes are complicated and are effected by certain active agents in the digestive secretions known as ferments or enzymes. In the mouth the food is chewed and mixed with the saliva. By a fixed reflex the character and composition of the food excites an abundant flow of saliva so that even solid food if properly masticated is transformed into a liquid mass suitable for swallowing. The function of the saliva is largely mechanical in getting the food into condition to swallow, but to a certain extent it exerts a chemical effect also. It contains a ferment or enzyme that converts starchy material, such as is present in bread and in our cereals and vegetables, into sugar. This is the way that all the starches must go before they are absorbed into the blood. A beginning is made in the mouth, but the process is taken up again and completed in the small intestine under the influence of the pancreatic secretion. When the food enters the stomach it is mostly undigested, but the act of chewing has brought

it into a favorable condition for digestion, and the more favorable the more carefully it has been masticated.

As we have seen the food stays in the stomach a long time on the whole. Some of it begins to pass out pretty soon, depending on the nature of the food, but with an ordinary diet it is several hours before the stomach is completely emptied. The changes that go on in the stomach are partly mechanical and partly chemical. The gastric juice is formed all over the interior of the stomach and is poured out in response to the stimulus from the food. The constant contractions of the stomach which have been described above serve to grind up the food, already softened and comminuted by chewing, and mix it thoroughly with the gastric juice. This secretion contains a ferment, the pepsin, which, together with an acid also present in the secretion, acts upon the soluble and insoluble proteins in the food and converts them all to a very soluble form, not, however, the form in which the protein is prepared for final absorption into the blood but an intermediate form. The digestion of the proteins like that of the starches is completed in the intestine. The function of the stomach, in fact, is mainly a preparatory one.

The food softened to the consistency of a thick soup and with some of its proteins and starches partially digested is shot out in spurts into the intestine where the final changes occur. These changes in the intestine are effected by a variety of specific ferments or enzymes furnished by the pancreatic juice and by the cells lining the wall of the intestine itself. In its slow passage along the 22 feet of small intestine there is abundant opportunity for the food to get thoroughly mixed with the secretions and to undergo its final changes. It will be remembered how neatly the tube handles this food, churning it

up at times and then shooting it along for a few inches, so that eventually every particle of food has a chance to be acted upon, and every particle of the new products formed has a chance to be absorbed through the lining cells of the tube into the blood-vessels that are imbedded in its walls.

The three important constituents of the food that have to be digested are the proteins, fats, and carbohydrates. The water and soluble salts and vitamins do not need to be digested, they are absorbed just so and mainly in the small intestine. As for the proteins, fats, and carbohydrates what happens to them is that the complex molecules of which they are composed are broken up into much simpler ones. The big carbohydrate molecules are broken up and converted into the much simpler ones of the sugar known as glucose, and as glucose practically all the carbohydrate goes into the blood and is eventually offered to the cells of the body for use. If we were to circumvent the natural process of digestion and with a syringe inject, say some cane-sugar, straight into the blood the cells could not use it, it would simply pass out again in the urine. A similar but more profound change happens to the protein foods. The very complex molecules of which these substances are formed are split into a number of much smaller ones, the process being analogous to the breaking up of a word into the separate letters of which it is composed. These simpler and very soluble substances then pass into the blood and are carried to the cells of the body which have the property of again uniting them to form the special kind of protein that the cell needs in its growth.

When one stops to consider it, it is a really remarkable process. All these many kinds of foods that we eat and pour into our stomach in a great mixture are carefully picked over and transformed into a small

number of simpler substances suitable for the nourishment of our cells. However varied our selection of food may be, the dietary of the cells of the body is relatively simple and the processes of digestion are directed to ensuring a uniform kind of nourishment for the ultimate little units of which we are composed. The chemistry of the process is difficult to follow, especially when it comes to the reactions that take place within the cells themselves. All the resources of science have been applied to their investigation, but it will be many a long day before we arrive at anything approaching a full understanding of the chemical changes that take place.

CHAPTER III

THE MECHANISM OF RESPIRATION

Oxygen and Carbon Dioxid

TO THE older physiologists the significance of the breathing movements was an insuperably difficult problem. It was not possible to understand it until chemistry had advanced far enough to explain the composition of the inspired and expired air. Now the story in its general outlines is perfectly clear. Air is breathed in to supply oxygen to the blood for the use of the cells of the body, and in the expired air carbon dioxid is given off as one of the waste products. This interchange takes place constantly during life. The essential thing in respiration is the taking up of oxygen and the giving off of carbon dioxid. The absorbed oxygen is carried by the blood to the different tissues, and in the cells it is used to oxidize or burn certain substances with the resulting formation of water and carbon dioxid, and these products in the long run are eliminated; the water through the lungs and skin as water vapor, and through the kidney as liquid water. The process is essentially the same as when wood or coal is burnt in the fire, only it takes place slowly and the heat evolved in the process is given off more gradually. In the body the amount of oxygen furnished by the respirations must be adaptable to the needs of the body; when, as in the case of muscular exercise for example, the combustion or oxygen consumption is more rapid the respirations must increase to furnish the necessary supply. The investigations of physiologists have demonstrated

that the whole process is beautifully regulated in all of its details through certain mechanisms that work automatically and with astounding success under normal conditions. Let us examine some of the mechanisms.

How We Breathe

In the first place there is the nerve-muscle apparatus that expands and contracts the chest in the movements of breathing. An inspiration, that is an enlargement of the chest, is made by the contraction of muscles which elevate the ribs and by a contraction of the diaphragm which increases the size of the chest in the vertical direction. In very quiet breathing it is the diaphragm which is most concerned; when the breathing is deeper the ribs come into action. These muscles are supplied with nerves which arise from the spinal cord and have continuations up to the base of the brain.

The rhythmic play of these muscle is controlled by a small group of nerve cells in the lower part of the brain, the *medulla oblongata.* This group of cells is called the respiratory center—it is in constant rhythmic action, now faster, now slower, according to the need of the body for oxygen. Its adaptation to the needs of the body is not controlled by any conscious effort on our part, it is regulated entirely by an unconscious mechanism. The center is kept in play by the reaction of the blood flowing through it, which in turn depends upon the amount of carbon dioxid in the blood, which in turn depends on the activity of the tissues. The greater the functional activity of the tissues, the greater will be the production of carbon dioxid in consequence of the increased oxidations. The arrangement is regulated so that activity provides the stimulus that increases the nervous discharges from the respiratory center,

and these give larger contractions of the diaphragm and the muscles that lift the ribs, and thus there are produced deeper and more frequent inspirations which provide a larger supply of oxygen for the blood. The processes run in an automatic circle. If this were not so the body could not meet the demands made upon it.

All the nervous and muscular connections involved are set to work smoothly and promptly when the natural stimuli come into play, but it is evident from experience that the mechanism works best when it is kept in practise. When a man who has led a sedentary life attempts any unusual exercise, running for a car for example, he is likely to suffer from breathlessness, and also from an unduly excited heart. A person used to muscular exercise could do the same act without any discomfort. On the other hand, there is of course a limit to the adaptability of the mechanism. In running races, especially the long-distance races, the contestants exert their muscles beyond the limit that is physiologically permissible, with the result that toward the end they show respiratory distress, because the mechanism, doing its best, can not furnish adequate amounts of oxygen or remove completely the great excess of carbon dioxid formed. If, therefore, one wishes to keep the respiratory machinery in as good a condition as possible to meet the ordinary emergencies of life, he must lead an active muscular life. If this need is not provided for by his vocation he should substitute sports or games of some kind or systematic exercise.

The Rôle of the Blood

This regulation of the breathing movements provides for an adequate supply of oxygen to the blood circulating through the lungs and for the removal of

the excess of carbon dioxid brought to the lungs by the blood, but it is obvious that the blood must transport these gases to or from the lungs. The way in which it discharges this function has long been one of the important subjects of study by physiologists. In regard to the means used for the transportation of the oxygen our knowledge is fairly complete. If the blood were simply a liquid in which the oxygen was dissolved it would be wholly inadequate to carry the large amounts of oxygen needed by the body, for the solubility of oxygen in aqueous solutions is very small, whereas in the course of twenty-four hours as much as 500 liters or about 18 cubic feet of oxygen must be carried by the blood.

The provision that has been made by nature for this purpose is the development of a special substance, *hemoglobin,* which is contained in the red corpuscles and gives to them their color. Hemoglobin is what the physiologists call a respiratory pigment. It has the property of combining chemically with oxygen, forming, however, a loose compound which readily breaks down and liberates the oxygen. Owing to the presence of this compound the blood can take up a large amount of oxygen, about one-fifth of its volume in round numbers, whereas without the hemoglobin it could absorb only about one one-hundredth of its volume. The hemoglobin is not dissolved in the liquid of the blood, it is packed into the red corpuscles. These corpuscles are very minute and very numerous. A small drop of blood contains several millions of them and if we consider the entire quantity of the blood in the body their number is uncountable.

In the blood that flows back to the heart from the various tissues of the body some of the oxygen has been removed. The heart sends this venous blood

into the lungs and there it is divided so minutely, by the breaking up of the lung arteries into capillaries, that finally when it is brought to the walls of the air-sacs of the lung the huge number of corpuscles all stream through the capillaries in single file, and each corpuscle with its load of hemoglobin is fully exposed to the air that has been breathed in. The exposure is very brief as it does not take any one corpuscle more than a second to pass through a capillary, but it is ample to enable the hemoglobin in each corpuscle to take up extra oxygen, under normal conditions practically all that it can carry.

This process goes on continuously all through our lives, waking and sleeping, the only variation that takes place is that sometimes, during muscular exercise for example, the current of blood flows more rapidly, taking up more oxygen because more corpuscles pass through the long capillaries. If breathing is stopped for a few minutes all the oxygen will be removed from the capacious lungs and death will soon follow, for the tissues must have a constant supply of oxygen to live. If the number of corpuscles is reduced by disease, as in the case of anemia, or by accident, as in the case of hemorrhage, then the supply of oxygen to the tissues is imperiled, since the number of carriers is diminished. The supply may be sufficient under such conditions to satisfy the body when it is at rest, but if the individual attempts any exercise, which means a demand for more oxygen, the demand can not be met, the person suffers from breathlessness after even a slight exertion.

Gas Poisoning

A similar result will follow, naturally, if anything interferes with the power of the hemoglobin to take up oxygen. This is what happens in so-called gas

poisoning. Ordinary illuminating gas contains a gas known as carbon monoxid which has the property of uniting with hemoglobin more firmly than does the oxygen. If a person breathes this gas the hemoglobin in all the corpuscles combines with it, and when the corpuscles stream through the lungs they can no longer take up a charge of oxygen, the hemoglobin is put out of business, so to speak, by its combination with carbon monoxid and as a result the tissues are deprived of oxygen and die. The respiratory muscles do their duty and bring a plentiful supply of oxygen to the blood, but the blood has no longer any means of taking up this oxygen and transporting it to the tissues.

Carbon monoxid, unfortunately, is a gas that we are apt to come into contact with very frequently under present conditions. Houses supplied with illuminating gas have their air vitiated more or less by small leakages from the fixtures, and automobiles give it off in considerable quantities in their exhausts, owing to the incomplete combustion of the gasoline. As every one knows, it is exceedingly dangerous to remain in a closed garage with the engine of the automobile running. In the great vehicular tunnel that is now being built under the Hudson River at New York the most serious problem is that of guarding against the accumulation of this gas from the automobiles using the tunnel. The only provision that can be made is to provide such abundant ventilation as will prevent the gas from accumulating to a dangerous extent. Whether or not the constant breathing of small amounts of carbon monoxid is dangerous to health has not been determined by exact observations. It is one of the problems of hygiene which should be settled, since in many of the occupations, and indeed for almost every one

under present conditions, there is a probability that at times more or less of this gas is inhaled.

Distributing the Oxygen

After the blood flows away from the lungs loaded to capacity with oxygen it goes to the left side of the heart and thence is distributed over the body through the branching system of arteries. When these arteries penetrate the different organs they divide eventually into very minute vessels, the capillaries, which ramify among the cells of which the organs are composed. The blood flows between the cells, therefore, in little vessels that are so small that the corpuscles can just about pass through them. At this point, or rather at these points, all through the body the blood gives up its oxygen to the cells and takes up the carbon dioxid from the cells. It is just the reverse of the exchange of gases that takes place in the lungs. The physiologists, of course, have sought out the reasons for this exchange. They find that it is governed by simple physical laws.

If one imagines a single capillary passing between a row of cells then a picture of what takes place will answer in general for the same process in all other parts of the body. The little rivulet of blood flowing through the capillary is separated from the cells only by the thickness of the wall of the capillary, which does not amount to more than about one twenty-thousandth of an inch. Inside the capillary the oxygen is held in the corpuscles in combination with their hemoglobin, but this is a compound which breaks down easily when the surroundings are deficient in oxygen. This is the case in the capillaries, since any oxygen in solution in the liquid outside the capillaries is taken up quickly by the cells, and this constant removal of the oxygen by the cells gives

occasion for the compound of oxygen and hemoglobin in the corpuscles inside the capillary to break down and liberate some oxygen. As the corpuscles file through the capillaries each one is unloaded of part of its oxygen which diffuses through the capillary wall and is taken up and used by the cells outside the capillary.

The chemical changes that are going on in these cells as long as they are alive are, it will be remembered, of the nature of combustions or oxidations. The oxygen that they absorb burns some of the material within the cells and the products of this combustion consist largely of water and carbon dioxid. This latter substance, therefore, is being produced constantly within the cells and must be removed, since if it rises above a certain concentration it is injurious. What happens is that the carbon dioxid diffuses from the cell, where it is being made, through the capillary wall into the liquid of the blood and there it is held or bound by the alkali of the blood and in this form is carried eventually to the lungs and given off in the expired air.

We can picture to ourselves that constantly during life the innumerable red corpuscles of the blood are discharging a double duty, they are transporting oxygen from the lungs to the cells of the tissues which can not live without this oxygen, and on the other hand they are transporting the injurious carbon dioxid from the cells, where it is being formed, back to the lungs where it is eliminated from the body in the expired air. When the cells are in activity, when the muscle cells are contracting, for example, or the gland cells are secreting, they need more oxygen and they give off more carbon dioxid. Provision for this increased exchange of the gases is made by augmenting the flow of the blood, so that the blood corpuscles travel more quickly through their

circuit and thus transport more oxygen one way and more carbon dioxid the other. Here as in the case of the other mechanisms of the body the adjustment of the supply of blood to the needs of the tissues is made automatically without any conscious intervention or knowledge on our part.

CHAPTER IV

THE BLOOD AND CIRCULATION

Blood Corpuscles

THE BLOOD is a most interesting liquid. Every one is acquainted with its appearance as seen by the naked eye. It has a red color which varies from a vivid scarlet when it flows from the arteries to a crimson color when it comes from the veins. The red color is due entirely to the infinite number of red corpuscles suspended in it. If one catches some blood as it flows from a vessel, and prevents it from clotting by adding certain non-coagulants to it, on standing the corpuscles sink slowly to the bottom leaving a colorless or slightly greenish liquid above. The blood consists, therefore, of a colorless liquid in which are suspended three different varieties of corpuscles: the red corpuscles, the white corpuscles, and the platelets. The red corpuscles are the most numerous. A small drop of blood contains millions of them. Each is a tiny flat disc, containing the hemoglobin about which so much has been said in the preceding section. The white corpuscles are spherical or globular bodies; there is about one of them to each thousand of the red. The platelets are minute little colorless discs, smaller than either of the other corpuscles and intermediate in number, that is less numerous than the reds and more numerous than the whites. The function of the red corpuscles is to carry the oxygen and carbon dioxid, as has been described above. The function of the white corpuscles and platelets can not be stated in such brief form, and indeed our knowledge

in this respect is incomplete. One thing that we can say about the white corpuscles is that they help to protect the body from disease germs that may have gotten into the blood. They literally eat these germs up, that is to say, they take them into their interior and there kill and digest them. But they doubtless have other functions which at present are unknown to us.

Composition of the Blood

In the liquid of the blood are contained numerous salts and organic substances. Roughly speaking, the weight of the blood is about one-twentieth that of the body. In a man weighing 140 pounds there would be about seven pounds, or something less than seven pints, of blood. This is contained within a closed system of vessels in which it circulates round and round with considerable rapidity. It forms a great waterway system through which the different parts of the body have commerce with one another. In it the foods and oxygen are carried to the tissues and the waste products are borne from the tissues to the glands of excretion. Materials are constantly being added to it and taken from it, and yet in spite of this active unceasing change its actual composition is kept astonishingly uniform. If we should try to increase greatly the quantity of the blood or to vary its quality by injecting liquids or solutions into it, we should find that in a surprizingly short time it had become adjusted to its former quantity and quality. Here, as elsewhere, we have efficient self-regulating mechanisms at work and the very complete way in which they combine to preserve a constant composition of the blood has only been appreciated by the physiologist in recent years. If one drinks an unusual quantity of water, for example, it will probably all be absorbed quite promptly into

the blood, and we might suppose that the volume of the blood would be increased correspondingly, bringing on a condition of plethora. There is no indication of such a result. Any tendency in that direction is met by the kidneys which as promptly secrete the excess of water and maintain the volume and concentration of the blood within certain small physiological variations. The same thing happens when foreign, non-toxic substances are introduced into the blood or when any of the normal constituents of the blood, sodium chlorid for example, are increased above their normal limit. The great excretory channels, the kidney, the skin, the lungs and the bowels all cooperate in this regulation, with the result, as has been said, that the volume and composition of the blood remain remarkably constant from day to day and year to year in spite of the very active change all the time going on, the constant absorption of water and foods from the alimentary canal and the constant production and elimination of waste products in the tissues.

In diseased conditions the character of the blood may change. In anemic conditions the number of red corpuscles is diminished to a small or a large extent in accordance with the severity of the anemia. The number of white corpuscles may be markedly increased in inflammatory conditions due to infections. The amount of sugar in the blood is distinctly increased in diabetes and so on. As our knowledge increases, blood examinations, microscopical and chemical, become more and more useful to the physician in making his diagnosis. Any one in middle life must have been struck by this difference between the new and the old practitioners of medicine. A generation ago the average physician did not think of taking a specimen of blood for examination, now it is a matter of routine in serious conditions.

Differences in the Blood of Animals and Humans

While the bloods of our ordinary animals are very much alike in appearance and composition, there are, as a matter of fact, important differences of a kind which can not be expressed in a chemical analysis. If one were to take blood from a rabbit and inject it into the circulation of a dog the result would be fatal for the dog, and vice versa. Any foreign blood injected into the circulation of an animal is likely to cause injury or death. The foreign blood, in the first place, causes the animal's own red corpuscles to dissolve, in spite of the fact that its blood and the foreign blood are so similar, in general, that a chemist might not be able to detect any difference in composition by usual analytical methods.

It has become a common practise in recent years to transfuse the blood of a healthy person into the circulation of a person whose blood has been depleted by illness or accident, or altered by diseased conditions. In such transfusions the donor, as the person who gives the blood is named, must be selected with care. In this respect human beings fall into four groups and in making the transfusion the donor must be selected from the group to which the patient belongs, otherwise serious results may follow. Whether or not two bloods are alike may be determined by mixing the corpuscle of one blood with the liquid, that is, the serum of the other. If the two bloods are in the same group nothing happens; if they belong to different groups the corpuscles will dissolve or lump together into masses. This and a number of other similar interesting and important reactions exhibited by bloods from different animals depend on the presence in the blood of characteristic organic compounds which exist in such small concentration that

they can not be detected by ordinary chemical means. It is clear enough, however, that there is a great deal left to be discovered in regard to the composition of blood in respect to these rather mysterious substances. The physiologist has many problems of this kind for future work.

Clotting

There is one obvious and important characteristic of blood that should not be left without a word of explanation, and that is its property of clotting when removed from the body. In the circulation the blood is, of course, liquid and stays liquid throughout life. But if an artery or vein is cut and some of this blood flows out into a vessel, in a few minutes it will set into a soft jelly which soon grows firmer, so that the vessel can be inverted without spilling the blood. This is the process of clotting or coagulation. Its value to the animal lies in the fact that small wounds, which are so liable to happen to us, are closed by the coagulation of the escaping blood and thus serious bleeding is prevented. The importance of this safety device is brought out by the troubles that befall those unfortunate individuals in whom the clotting power of the blood is markedly diminished. Such individuals are named bleeders or hemophilics. Even a slight wound causes a serious and often a fatal hemorrhage. This curious condition runs in families, that is, is hereditary. It is transmitted in a certain definite way. It is shown only by males, but a male bleeder transmits the peculiarity through his daughters, who do not show the defect, to his grandsons, in accordance with a known law of heredity.

Coagulation is a striking phenomenon which it has been found difficult to explain completely because the process is so very complex. The main difficulty

has been to understand what starts the process of gelatinization in the blood when it escapes from the vessels. The general belief now is that the beginning of the whole process is due to the fact that the little platelets in the blood, the so-called third form of corpuscle, are very delicate structures. When removed from their normal environment they swell up, dissolve, and liberate a substance which starts a chain of processes that ends in the jellying of the blood. It is not possible to explain this series of changes without going into details of the chemistry of the blood. It must suffice to say that the end reaction is the precipitation of one of the proteins of the blood in such a form as to cause the liquid to change into a solid jelly. The blood is always prepared to give this reaction. We may go for days or weeks or months without any injury that would cause a hemorrhage, but no matter what changes may be taking place in the blood it always contains and preserves the several materials necessary to form a clot when the emergency arises, altho as far as we know these materials have no other use in the economy of the body. It is a part of the general mechanism of the body that is maintained by self-regulating and constantly acting processes, but the machinery in this case is of a chemical and not a mechanical nature.

Circulation of the Blood

When we consider the circulation of the blood, the distribution of the blood-vessels in which it is carried, and the pump, that is, the heart which keeps it in constant motion, we have to deal with a mechanical apparatus of beautiful structure and of extraordinary efficiency. The general nature of this apparatus is known, perhaps, to everybody. The blood is carried away from the heart in the arteries.

They start out as a single trunk that divides and subdivides into smaller and smaller arteries which end finally in minute capillaries. Each capillary is very tiny in diameter so that the small corpuscles can just squeeze through, but they are so very numerous that if they were all combined into a single tube they would make a channel several hundred times the diameter of the large artery which leaves the heart. One consequence of this arrangement is that the blood which leaves the heart in a rushing stream, moving something like a foot a second, is greatly slowed down in the capillary regions, that is in the interior of all the tissues, where its velocity is only about one-fiftieth of an inch per second. It is like a rapidly flowing river emptying into numerous irrigating ditches. This slower movement of the stream in the capillaries is important because it is there that all the interchange of oxygen and food and waste products that makes up the chemistry of the life processes takes place. When the blood emerges from the capillaries the reverse process occurs. It empties into small veins which unite into larger and larger ones until finally all the blood is gathered into two large veins that open into the heart. As the blood passes into the larger veins its velocity again increases.

Veins and Arteries

The arteries and veins, in fact, are simply conduits to carry the blood to and from the large capillary lake of the body in which the business of life is carried on. This arrangement of arteries, veins, and capillaries is not a fixed system, delivering always the same amount of blood in the same time. Such an arrangement would be far from meeting the needs of the organism. When the muscles are in action they need a lot more blood than they do at

rest. When the stomach is digesting it needs more blood, and the same is true of all the other organs of the body. The machinery must be adapted to supply blood in proportion to the need of each tissue for food and oxygen. This adaptation is provided for by certain regulatory mechanism which it has been the business of the physiologist to search out and explain. He has been able to do this by means of experiments and observations made on man and the lower animals.

The arteries and veins and capillaries are provided with nerves through which they can be made to contract and dilate, and in this way the blood flowing through them can be increased or diminished in quantity. These nerves are stimulated reflexly and the mechanism is so arranged that when a tissue is in action its small arteries and capillaries will be dilated and thus receive more blood. Nerves that have this action are spoken of as vasomotor nerves, and through the unconscious activity of this vasomotor system of nerves the supply of blood is controlled in large measure and diverted into this or that region according to its needs. The regulation is in reality more complex than this, as at least two other important factors cooperate. The diameter of the smaller blood-vessels and especially the capillaries is increased in active organs as the result of the chemical reactions that occur in the tissues, so that automatically the more a tissue works the more of these chemical stimuli will be produced. And then there is of course the heart, the pump of the system. It also can be made to work more slowly or more rapidly as the case may be, by means of nervous reflexes, and thus gives to the whole mass of blood a greater or less velocity. All of these regulations come into play in ordinary life

so that our vascular system is an exceedingly elastic mechanism, far superior in this respect to any irrigation system that man has been able to construct.

The Heart and How It Acts

The heart constitutes the center of the circulatory system, the point from which the arterial blood starts out on its circuit and the point to which the venous blood returns. It is a hollow bag or ball of muscle provided with valves, so that when it contracts the blood is forced out in one direction, and when it relaxes other blood is sucked in from another direction, just as in the case of a syringe-bulb that one squeezes with his hands. The structure of the heart is complicated by the fact that it runs two more or less independent circulations, one through the lungs, known sometimes as the lesser or pulmonary circulation, and one through the body at large, known as the greater or systemic circulation. The heart is accordingly divided into two parts by a partition or septum, so that we have a right side, or as we say for convenience sake, a right heart which serves as the pump for the pulmonary circulation, and a stronger, more muscular left heart which supplies the systemic circulation. But the two sides are so connected that the blood sent by the right heart to the lungs is returned by the veins to the left heart and sent out into the greater circulation. This, in fact, is the underlying reason for the double circulation. The blood that comes back to the right heart from the greater circulation is venous blood which has lost part of its load of oxygen and taken on a large amount of carbon dioxid. The right heart sends it to the lungs where it gives up its excess of carbon dioxid and takes on a full supply of oxygen. It is returned to the left heart as arterial

blood and is sent out over the greater circulation to give oxygen to all the tissues.

Outside its mechanical structure as a pump the two most interesting and perplexing things about the heart are, first, its property of giving rhythmic pulsations; second, its power of adjusting both the rate and the strength of its pulsations to the demands made upon it by the body. As in the case of the other mechanisms of the body the thing that most impresses the student of the subject is the beautiful way in which the organ regulates itself. One can understand, of course, that in the heart as in the other organs this must be the case, otherwise the body could not accommodate itself to the changes in external conditions. It would break down. If nature had not managed to create these self-adjusting devices she could not have evolved the higher forms of life, but however commonplace this generalization may be it does not lessen at all the wonder and surprize that comes to one when he realizes at first hand the delicacy, perfection, and oftentimes the mysteriousness of these self-acting and self-adjusting arrangements.

As for the rhythmic property of the heart muscle, its power to beat spontaneously in a definite rhythm, we can not explain it at all. We know a great many things about the conditions which favor or oppose the rhythmicity, but practically nothing about the nature of the chemical or physicochemical forces within the tissue itself that give this curious result of alternating contraction and relaxation, or as we say in the case of the heart, alternating systole and diastole. A great many living cells, especially among the simpler animals, show this property, but in the higher animals it is the heart in which this peculiarity is most highly developed. Beating at the rate of

70 to 80 times a minute it keeps up its automatic activity throughout a long life. Certainly this is a wonderful mechanism. While all parts of the big muscular heart are capable, under proper conditions, of giving these pulsations, rhythmicity is most highly developed in a small area in the wall of the right auricle, and this bit of tissue acts as a pace-maker for all the rest of the heart. In it a contraction arises spontaneously and then spreads in an orderly fashion and through a definite conducting system to the rest of the muscle, and under normal conditions the regularity of this procedure is never interfered with no matter how slow or how fast the heart beats. But under pathological conditions all kinds of irregularities may arise which interfere with the proper function of the heart and give distress to the individual or cause death. It is the part of the physiologist and physician to work out the causes of these irregularities and in many cases this has been done with great success, while in others the explanations are still hidden from us.

It is practically self-evident that the heart must be able to change its rate and force of beat to accommodate itself to such extreme conditions as a quiet sleep on the one hand and a running race on the other. If it just beat at a fixed rate and sent out always the same amount of blood at each contraction then there would be an oversupply to the tissues during rest and possibly an undersupply during activity. Changes in the rate of beat are effected through two nerves which supply the heart, both of them constantly in action, one tending to make the rate slower and one tending to make it faster. The body often makes use of balanced mechanisms of this kind as they undoubtedly respond more promptly and smoothly than a one-sided adjustment. As every one knows all kinds of conditions affect the rate of

the heart-beat, muscular activity, emotions of all kinds, fevers, etc.

The value of this arrangement for the body as a whole is that the rate of heart-beat, and therefore the rapidity of the circulation and the abundance of the supply of oxygen, is adjusted to the needs of the tissues. In conditions of rest the heart beats at a certain rate which is slower than would be the case if the nerves going to it were not acting. They keep a brake on the heart's activity and during muscular activity or emotional excitement this brake is relieved, thus allowing the heart to beat more rapidly. In the case of muscular work the value of this regulation is apparent; the working muscles need more oxygen and can get it only through an increased circulation of the blood. The physiological benefit of an increased heart-rate in emotional excitement is not so evident. Bearing in mind man's origin and the strenuous struggle for existence imposed upon our remote ancestors it may be assumed that emotional excitement was usually associated with danger and the need of putting the body into the best possible condition for fight or flight. However this may be it is a matter of common knowledge that emotions reflect themselves, so to speak, in the action of the heart and for this reason no doubt mankind came to consider the heart as the seat of the emotions, an idea that has now become imbedded in our literature and language. The heart in fact does serve as a sort of index of the state of the emotions, revealing to ourselves and perhaps to others the extent to which these emotions are aroused. In time of danger the way in which the heart behaves may express the difference between a brave man and a coward. But whatever the effect of the emotions may be they are transmitted to the heart through the nerves going to it.

Taking Care of the Heart

The heart has another and more direct way of regulating its work in accordance with the demand made upon it, a mode of adjustment in which it is far superior to ordinary mechanical pumps. During its period of relaxation it is filled with blood from the veins emptying into it and this blood stretches the heart, of course, in proportion to its amount. Now the physiologists have found that the more the heart is stretched the stronger will be its contraction or beat. This is just what happens in muscular work. The more the muscles contract the greater will be the flow of blood to the heart and the more it will be stretched so that in this way the work of the heart is increased in proportion to the need.

The heart is therefore not only a very beautifully constructed mechanism for pumping but it is self-regulated to work according to the demand put upon it. Experience shows us, however, that with this as with the other mechanisms of the body the regulating devices work well only when they are in training. If a person leads a very sedentary life his heart will not respond well when a strain is put upon it, when it is called upon to deliver promptly an increased amount of blood. This point was referred to briefly in the chapter on respiration. If one wishes to maintain his heart in a good responsive condition it is necessary to keep it in training by adequate muscular exercise. Games and sports and systematic exercise have a most direct beneficial influence upon the organs of circulation. One can live of course without such things, but without them he is not in a condition to meet well any emergency that calls for active muscular work.

CHAPTER V

THE CENTRAL NERVOUS SYSTEM

Nerve Cells

UNDER the term central nervous system we include the several parts of the brain that lie in the skull and the long spinal cord continuous with the brain that lies in the spinal canal or back-bone. The characteristic cell of this system is the nerve cell. There is an infinite number of them and they vary greatly in size and shape. These cells possess branches or fibers that connect one with another and we know that during life what we call nervous impulses are passing to and fro throughout this mass, giving rise to sensations and motions and reflex actions of various kinds. When one looks at a bit of brain or spinal cord under the microscope it would seem to be a hopeless problem to bring any order out of the intricate network of cells and fibers, but physiologists have been able to accomplish this task with a large degree of success.

The brain gives off twelve pairs of nerves which connect it with various parts of the body, and the spinal cord gives off some thirty-one pairs of nerves which connect its cells with the different tissues of the body. Each of these many nerves contains thousands of nerve fibers and all this great number of fibers represent a system of connecting links by which the body can influence the activity of the brain or by which the brain can influence the activitv of the body. For, numerous as they are, they all fall into two classes, one the afferent or sensory fibers which bring impulses into the brain or spinal

cord, and the other the efferent or motor fibers which carry impulses out from the brain or spinal cord. The older physiologists thought that these fibers were minute tubes which conveyed some very rare kind of liquid, the vital or animal spirits, but we know now that they are solid fibers of very delicate structure, and the thing that they convey is an electrical charge which we call a nerve impulse. In a warm-blooded animal this impulse travels very rapidly, about 300 feet a second, so that it does not take much time for it to pass from the brain to an outlying tissue or vice versa.

Central Control

Speaking in a general way, the central nervous system forms a great controlling or coordinating mechanism for the whole organism. The various organs and tissues of the body are brought into relation with one another through two connecting systems, the blood and the nerves. Through the circulating blood that bathes all the cells and is kept in ceaseless motion it is evident that products formed in one tissue can be carried to the other tissues and influence their activity. Food and oxygen we have seen are carried in this way, and waste products are picked up and brought to the organs of excretion. The nervous system constitutes another connecting link whereby activity in one tissue affects other tissues through the nerve impulses or nerve messages that are transmitted from one to the other via the central nervous system.

Reflexes

The typical example of the way in which the nervous system acts is given in what we call a reflex action. By this term we mean the conversion of an afferent or sensory impulse, brought into the

central nervous system through some afferent nerve fiber or fibers into an outgoing or efferent impulse which passes to some muscle and makes it contract, or to some gland and makes it secrete. The incoming impulse from some sensory surface is reflected as it were in the central nervous system and is sent out again as an outgoing impulse which sets some tissue into action. For example, if one takes a little acid in the mouth it makes the saliva flow. We would not get this reflex if the brain were destroyed. What happens is that the acid in the mouth acts on the endings of sensory nerve fibers and starts a series of impulses toward the brain. In the part of the brain in which these fibers end they connect through nerve cells with outgoing fibers that end in the salivary glands. So the incoming impulses are converted to outgoing impulses that pass to the glands and start them secreting. The reflex would be prevented by a destruction of the part of the brain concerned, or by cutting the sensory nerves supplying the mouth cavity, or the motor nerves going to the glands. The reflex path, or reflex arc as it is called, constitutes a circuit and the reflex will be prevented if the circuit is blocked at any point. The fact that the sensory impulses in this case take a definite path after reaching the brain, a path which is always the same, instead of ramifying all through the network of cells and fibers, is proof that we have a mechanism blocked out which will always react in the same way to the same stimulus. It is just like a definite electrical connection made through a switchboard, where if you throw the right switch you will always get the same result.

We are born with hundreds of these reflex mechanisms all connected up and ready to act as soon as the proper sensory stimulus is applied. Place a

nipple in a baby's mouth and it begins to suck, because a definite reflex mechanism is started into action by the contact of the nipple with the sensory surfaces of the mouth. Tickle the bottom of its feet and the foot will be drawn away by reflex action. Touch the front of the eye and the eyelid will be closed by a reflex action. Many of these reflex movements or secretions are recognized by us, that is, we are conscious that they are taking place, but there are many going on constantly of which we are entirely unconscious. When the acid stomach-contents pass into the intestine they stimulate the sensory fibers of the mucous surface and cause a reflex contraction of the gall-bladder and a spirt of bile into the intestine. We know nothing of this process altho it goes on repeatedly during a meal. These inherited reflexes are fixed and definite mechanisms that play a most important rôle in the economy of the body. The animal could not live and function as an organism without their assistance in coordinating the activity of one tissue with that of another. On account of their determinate and invariable response they are spoken of as a group under the term of "unconditioned reflexes."

Training the Reflexes

The spinal cord and the basal portions of the brain are made up in large part of these inherited reflex arcs which carry on the business of life for us and unify the activities of the various tissues and organs. But when we study the functions of the higher parts of the brain, the great hemispheres or cerebral hemispheres, we find a different state of affairs. There are inherited reflex arcs in this part of the brain which give unconditioned reflexes, but there are also large numbers of nerve cells that

are not connected up in this fixed manner, but are in what we may call a plastic condition, that is, they can be molded into one or another kind of a reflex arc according to the kind of stimulation to which they are subjected. They can be trained to give a certain response by repeated applications of the same stimulus, and if a long interval elapses without the application of the stimulus they may lose the power of giving the proper reaction. In other words they can be educated in different ways, and the reflex acts thus developed may be designated under the general term of conditioned reflexes since their nature is conditioned by the circumstances which set them into activity. From infancy onward this process is taking place. The formal education of the schools and the experiences of life combine to establish in this unformed area a set of association paths which physiologically are of the nature of reflex arcs and whose combined activity represents the mentality of the individual. What is made out of this part of the brain depends in part on its structure to start with, for we have every reason to believe that this differs in different individuals, and in part upon the experiences or stimulations to which it is subjected, that is upon environment and education. The best educational training and the most favorable environment can not by their combined influence make a genius out of a mediocre brain, any more than we can make a silk purse out of a sow's ear, but there is no doubt that in each brain the possibilities of development are in the beginning in potential form and the extent to which these possibilities are realized will depend largely on the training and experience to which the individual is submitted. Hence the importance of good environment and good training.

The Brain

If one were to enumerate all the functional activities of different parts of the brain it would make a long list and would imply a consideration of pretty nearly everything going on in the body, since the nervous system as a sort of middleman is involved in the reactions of the organs upon one another. But it is desirable to refer briefly to some few parts whose functions are of especial importance and interest. Where the spinal cord enters the skull it widens out a bit to form the first part of the brain, the bulb or *medulla oblongata.* In this bulb there are several groups of nerve cells, nerve centers as they are called, which are of particular importance in the life of the body. One group constitutes the respiratory center. It is connected by outgoing fibers to the various muscles that carry on the respiratory movements of the chest. These nerve cells are in constant rhythmic action discharging impulses to the respiratory muscles. If they stopped action respirations would stop and the individual would die for lack of oxygen. A very small injury to the medulla may be fatal, or any serious injury of the spinal cord below the medulla, in the neck region, which will cut this center off from its connections with the respiratory muscles will also cause death from suspension of the respirations. This is the physiology of death from hanging when it works properly.

In the same region of the medulla is another important group of nerve cells, the vasomotor center, which regulates the size of the blood vessels throughout most of the body, and a third center through which the heart-rate is controlled by reflex action. This part of the brain, therefore, is most essential in maintaining the existence of the complex of organs

of which the body is composed, in establishing that communal life which unites them as a single organism or individual.

Gray Matter

The most interesting functions of the brain are discharged by the large cerebral hemispheres. These structures are more highly developed in man than in any other mammal and form the mechanism through which our conscious sensations and all the processes of thought and reflection are mediated. Their external layer or cortex is composed as we say of gray matter consisting of several strata of nerve cells of different sizes and shapes. This cortex is about one-eighth of an inch thick and is thrown into numerous folds or convolutions. If one could scrape off this thin layer of gray matter he would thereby wipe out consciousness and power of reasoning, and reduce the individual to a mere animal machine without mind. If this statement is correct, then this gray matter of the cortex is the most wonderful substance in the world, or as far as we know in the whole universe.

Living matter has many remarkable properties, such as its power of maintenance and growth, its ability to move and reproduce its kind, but the two properties which are most mysterious are those designated by the terms, heredity and consciousness. By heredity we mean the power of a fertilized egg to produce a replica of its parent; by consciousness, the fact that certain cells, the cells especially in the cortex of the cerebrum, when in activity produce a change in our subjective being. We can conceive that explanations may finally be obtained in terms of physical and chemical laws of the changes of nutrition, secretion, motion, reproduction, and even perhaps of heredity, but we have no grounds at present

for believing that we shall ever understand the relation between mind and matter, the connection between the objective change in the brain-cells and the parallel reaction in consciousness. Philosophers and scientific men have endeavored to theorize about this relationship, but it still remains a mystery, the greatest mystery of existence. Physiologists attribute the function of consciousness, if that term may be used, mainly to the cells of the cortex of gray matter in the cerebrum, because it is known that injuries to or abnormalities in structure of this portion of the brain cause changes in the individual's mentality, but whether some degree of consciousness is or is not mediated through other portions of the brain remains undetermined.

The Remarkable Cortex

With great labor and with the aid of many different methods of investigation they have worked out with fair success the various locations in the cortex in which the different tracts of sensory nerves make their final endings. Thus the nerves from the eyes end in one region, those from the ears in another, those from the skin in another and so on. So that the cortex has been mapped out into different sensory areas in each of which it may be assumed a distinct kind of consciousness is aroused by the incoming impulses from the various sense organs. But all these sensory areas, as well as the motor areas from which the outgoing impulses to the voluntary muscles originate, are richly connected with one another by nerve fibers so that their activities are associated or integrated under normal conditions, and there is little warrant for dividing the mind into a number of different faculties and assigning each to a special part of the cortex, as was attempted by the old phrenologists. But these labors have been

very useful to the physician in diagnosing the location of injuries to the brain such as may result from wounds or hemorrhage or tumors. By a careful analysis of the symptoms shown by the patient in such cases it is often possible for the specialist to locate the seat of the lesion. This diagnosis is made most easily in the case of paralysis resulting from injuries to the brain.

It is known in the first place that the cortex of the right side of the brain, or right hemisphere, controls the muscles of the limbs of the left side, and vice versa. Then in each hemisphere, in what is called the motor area of the cortex, the part that controls the movements of the toes, for example, is quite separate from that governing the hands or the lips. So that reasoning back from the part that is paralyzed it is possible to locate exactly the spot in the cortex that is affected.

Considering the remarkable function performed by the cortex one might suppose that a microscopic examination would reveal a highly complicated structure differing perhaps in a distinctive way for the several areas, but, on the contrary, the structure is relatively simple, consisting of several superimposed layers of cells, and is pretty much the same all over the cortex. There are differences of a minute kind, in different regions, in the thickness of the strata, for example, so that an expert might be able to say from what area of the cortex a given specimen was taken, but on the whole the arrangement is quite uniform, and much the same in lower animals as in man. As one looks at such a specimen under the microscope he is lost in wonder that a structure so simple can act as a medium for all intellectual activities. One speculates as to the meaning of the several strata and the part that each may take in the mental and emotional reactions, but on this question we have

no information. One of the few generalizations that may be made from the anatomy of the cortex is that the higher the mental development of the animal the more numerous and richly branched are the processes given off by the nerve cells. We can see some meaning in this fact, for the branches of the cells are the means by which they communicate with one another and influence each other's activity. They form the anatomical basis for associating the reactions of the brain, and the difference between the mental activity of a frog and a man is in the long run largely a difference in the complexity of the associations aroused when through some avenue of sense the brain is brought into action.

The Cerebellum

There is another part of the brain about which a wo:d should be said, namely, the cerebellum. This large organ lies in the posterior or occipital region of the skull just above the *medulla oblongata.* In spite of its large size it is not essential apparently to the sensory or intellectual functions of the brain. It can be removed in the lower animals without the production of any obvious disturbance in the animals' sensations or mental activities. Its functions are connected with the proper use or combination of the muscles of the body in executing movements of locomotion or equilibrium. When we stand or walk or run or execute any movements, skilled or unskilled, in which a number of different muscles cooperate it is obvious that their separate actions must be combined properly, as to strength and as to time, to give an orderly and adequate result. From this point of view even a simple movement of a limb is quite a complicated affair. Now in some way the cerebellum is concerned in this orderly coordination of the muscles in executing movements. If the

cerebellum is injured, or excised in part or in whole, the obvious result is a disorderly and inefficient use of the muscles, which may exhibit itself simply as an unsteadiness in gait, or as violent uncoordinated and useless contractions, according to the extent of the injury. None of the muscles are paralyzed as would be the case if the motor area of the cerebrum were injured, but the animal is unable to use them in the various graduated combinations and sequences necessary to the performance of the intentional movements of the limbs and trunk. The exact nature of the nervous machinery involved in these coordinations has not been worked out by the physiologists with entire success. The anatomical connections of the cerebellum are very complex and several theories are proposed to explain just how this organ is concerned in the combination of muscular movements, but it is impossible to go into these theories on account of the number of anatomical and physiological details it would be necessary to consider. We may say in general terms that the function of the cerebellum is concerned with the coordination and adaptation of the muscles when they act together in movements of equilibrium or locomotion.

CHAPTER VI

THE SENSE-ORGANS

What They Are

THE SENSE-ORGANS taken together constitute a mechanism or apparatus through which we obtain information of what is going on in the world outside of us. It is curious to reflect upon the processes involved and the nature of the information furnished to us. When light falls on the eye, for example, what really takes place? The rays of light from a stone or a tree penetrate the eye and impinge on the retina. That sensitive organ is stimulated and a group of nerve impulses, which are of the nature of electrical changes, are transmitted along the optic nerves into the brain and finally terminate in certain nerve cells in the cortex of the occipital region of the cerebrum. The chemical or physico-chemical changes set up in these cells arouse in us a state of consciousness, a sensation of vision of a definite kind, and through connections made with other portions of the cortex stir up also associations of various sorts, memories of past experiences and thoughts and reflections which as a whole give us a mental or psychical picture that we attach to the object that we are looking at. It is evident that the real process of seeing takes place in the cortex, and the connection between this process and the tree or stone is very indirect.

Normal persons all get the same or nearly the same reaction from the same source of stimulation, except in regard to the accompanying associations

which depend upon past training and experience. The yellow primrose by the river's brim is only a yellow primrose to the simple peasant, but to the poet it is a symbol rich in associations and suggestions. As the philosophers long ago pointed out, the immediate knowledge that we get of the external world through the avenues of sense, and they are our only sources of information, is only a mental image; we can not in this way know anything of the real nature of the external universe. The retina is, so to speak, a push-button which when acted upon sets the nerve cells of the cortex into activity with a resulting visual sensation, but we have perhaps no better reason for assuming that the mental picture is like the external object than we have for identifying the vibrations of an electric bell with the nature of the object acting on the push button. If through some pathological process the same cells in the cortex were set into activity we might see a tree or stone or indeed a whole series of objects and events which had no objective existence at all. In this way we account for the hallucinations and false visions so often described.

However this may be, it remains certain that our knowledge of the external world does come to us primarily through the sense-organs; they furnish the raw material from which our mental fabrics are constructed. It seems to us that this knowledge is quite complete, but as a matter of fact this is not wholly true. There are light waves whose period of vibration is too short to affect the eye, and sound waves too rapid to act upon the ear, and magnetic changes which are wholly lost to us because we have no sense-organs for their perception. There is, in fact, a good deal going on in the outside universe about which we have no immediate information, but not knowing it is there we do not miss it of

course. What the eye doesn't see, the heart doesn't feel, as the old adage puts it.

The sense-organs through which these impressions come in from the outside are the eye for light, the ear for sound, the nose for odors, the tongue and palate for tastes, the tactile nerve fibers of the skin for pressures, and the warm and cold fibers for changes in temperature. They serve us not only for information but also for protection, and under this latter category we should put the nerves of pain, for painful sensations are most valuable in giving us warning of changes or occurrences that may do us serious harm.

Structure of the Sense-organs

Some of our sense-organs are very simple in structure, being formed, as in the case of the temperature and tactile fibers distributed over the surface of the skin, of delicate branches of the nerve fibers which lie between the cells of the skin in a position where they may be acted upon by anything that comes into contact with us; but others, especially the eye and the ear, have a very specialized structure to fit them to respond to their particular stimuli. Light may play upon the skin or any tissue or upon the optic nerve itself without producing any change that will affect our consciousness, but in the retina of the eye there are present modified nerve cells which are especially adapted to be affected by light vibrations.

The Eye

No one can study the structure of the eye without being deeply impressed by its beauty and perfection. It is difficult to comprehend how it could have been created by chance variations and selection even when we allow for the hundreds of thousands of years that intervened between the appearance of

the primitive forms of life and the development of the vertebrate animals. It is not possible to give a full description of the eye without the use of figures or models or dissections, but its general features are easily explained.

We have in the first place the globular eyeball resting in its bony socket and penetrated at its posterior pole by the large optic nerve. The eyeball lies somewhat loosely in the socket, resting upon a pad of fat and tissue so that it can be rotated smoothly in different directions or around different axes by a number of small muscles which are attached to the outside of the ball. In a general way we may say that it consists of two essential parts, namely, the retina, which is the sentitive surface affected by the light, and an optical part constructed so that it throws an image of external objects upon the retina. After the optic nerve penetrates the eyeball from behind it expands into the retina, or perhaps it would be better to say it merges into the retina which is spread out as a thin layer on the inside of the ball. Light entering the eye from the front must strike upon the retina after traversing the interior of the ball.

Thin as the retina is it is composed of a number of different layers, the most interesting of which is the layer of rods and cones, since it is here that the light acts and sets up a stimulus. Curiously enough these rods and cones are turned away from the entering light, that is to say, the light must penetrate all the other layers before it reaches the rods and cones. When it does reach them it sets up a change which is then propagated back toward the brain in the fibers of the optic nerve as a series of nerve impulses. When these impulses reach the cortex of the cerebrum they arouse conscious visual sensations. The retina lines the whole of the in-

terior of the eyeball, so that it forms a relatively large surface, all parts of which are more or less sensitive to light.

But when it comes to seeing accurately the size and shape of external objects, it will be found by a little observation that we make use of only a very small part of the retina for this purpose. This small area, only one-seventieth of an inch in diameter, lies in the center of the retina and is known as the fovea or central fovea. If one looks at a printed page and holds his eyes steadily on a certain letter he will note that while this letter and one or two of the letters on either side of it are seen plainly, those at a little distance away are blurred, and toward the margin of the page nothing at all can be seen distinctly. The letters that are seen clearly are those whose images fall on the fovea, while those falling on the rest of the retina are seen indistinctly and the more so the farther one gets away from the fovea. It is our custom therefore in examining any object to move our eyes about, to let them roam over the field so that point after point falls on the fovea and is seen clearly. In reading lines of print we keep moving the eye from side to side to bring one word or one part of a word after another upon the fovea.

Vision

When the eye is held fixed in any given position the physiologists speak of all that part of the external world whose image falls upon the fovea as the field of direct or central vision, while the much larger part whose projection falls outside the fovea constitutes the field of indirect or peripheral vision. We do not make very much use of this indirect field. Vision in it is blurred as regards configuration, but it is good in the matter of motion or changes in intensity of the light. If anything of this latter

kind happens in the indirect field so as to attract our attention what we do immediately is to turn the eyes or the whole head so that that particular part of the world will fall on the fovea and be seen distinctly.

In one part of the retina, on the nasal side of the fovea, is a genuine blind spot, that is a region which the light does not stimulate at all. It is the point at which the optic nerve penetrates the eyeball. If an eye is kept in a fixed position it is easy to demonstrate the existence of this blind spot by moving a small object round in the indirect field until its image falls on the spot when it will disappear from view. We do not notice this blind spot in ordinary vision, mainly because it lies in the indirect field where our vision of form and outline is so imperfect anyway. Our attention is concentrated on the objects whose images fall on the fovea.

The optical part of the eye is an extraordinary structure. One can understand in a general way, remembering the responsiveness and variability of living matter, how a surface like the retina sensitive to light may have arisen by variations that were inherited; but how the ingenious and complex optical devices of the eye were fashioned by gradual transitions is almost beyond imagination. Nature seems to have tried its hand at two very different devices, for the optical parts of the invertebrate eye, as seen in insects and crustacea, are entirely different from those found in our eyes and those of the other vertebrate animals. Without going into the anatomical details it may be said that the eye has two refractive surfaces or lenses which are perfectly transparent, namely, the cornea which form the front of the eyeball, and the crystalline lens which lies in the interior of the eyeball back of the cornea. These two surfaces act together as a lens which forms a perfect image of external objects and projects it

upon the retina, just as the lenses in a photographer's camera form such an image and project it upon the sensitive photographic plate. When the eye is at rest and has a normal structure the lenses have just the right power to focus distant objects perfectly upon the retina and give us distinct images and therefore distinct vision of them.

Near-sight and Far-sight

When the eye is near-sighted the retina is too far away, because the eyeball is more elongated than it should be, consequently the images upon the retina are not well focused and distant objects are seen indistinctly. This defect is easily remedied by the optician by placing proper glass lenses, concave lenses, in front of the eye so as to throw the image farther back and focus it upon the retina.

When the eye is far-sighted the opposite trouble exists, the eyeball is shorter than it should be and the image formed by the lenses of the eye falls upon the retina before it is brought to a focus. This defect is also easily remedied by placing proper glass lenses, convex lenses, in front of the eye to bring the image into focus on the retina.

Astigmatism

In an astigmatic eye the optical or refractive difficulty is a little more difficult to understand. It is due to the fact that the lenses in the eye have unequal curvatures in different meridians. In the normal eye the front of the cornea and the front of the crystalline lens are parts of a true sphere, that is, the curvature is identical in all meridians, so that no matter what may be the paths of the rays of light entering the eye they are all brought to a focus at the same distance. But in an astigmatic eye the front of the cornea has more of a cylindrical shape,

the curvature being greater along some meridians than along others, the result being that all parts of an external object will not be brought to a focus at the same distance, so that it can never be seen distinctly all at once. If the astigmatism is slight, the blurring of the object will be slight and will make no very great difference except in fine vision, as in lace making for example; but if the astigmatism is marked it gives great discomfort, even in such vision as is required in reading, and it must be corrected, otherwise secondary troubles, such as headaches, will develop. Fortunately the proper correction can be made with great exactness by a competent ophthalmologist. He measures the different curvatures of the cornea and then places before the eye cylindrical glasses so selected as to compensate for the defects of the cornea and restore it practically to a spherical shape.

These optical or refractive errors of the eye, short-sightedness (myopia), far-sightedness (hyperopia), and astigmatism, are all capable of being corrected very readily, and it adds greatly to the happiness, health, and efficiency of an individual to have glasses made which shall restore the eye to normality in this respect. It goes without saying that glasses that are improperly made either fail to make this correction completely or perhaps add to the defects and make the vision worse than it would be without glasses. Hence the importance in this matter of selecting a skilful and competent physician to make the examination of the eye and write the proper prescription.

Old-sightedness

In the normal as in the defective eyes it is quite necessary to have a focusing device to see clearly objects at different distances. As was said above

a normal eye is set to see distant objects clearly. If such an eye could not change then all near objects would be seen indistinctly, their images on the retina would be blurred. We can, of course, see near objects clearly as well as far objects, and we owe this power to the fact that in each eye there is an arrangement to increase the refractive power for near objects. This power of focusing or accommodating the eye is furnished by a little muscle within the eyeball which can be made to contract voluntarily. As it contracts it acts indirectly on the crystalline lens and increases its curvature, the more so the stronger the muscle contracts. When an object is as far away as twenty feet we do not have to use this muscle, it can be seen distinctly with the eye at rest. But as the object is brought nearer the muscle contracts more and more, thus increasing the power of the crystalline lens and keeping the image of the object on the retina in perfect focus. Naturally there is a limit to this power, as every one knows. If an object is brought very close to the eye it can not be seen distinctly, it has gotten inside of the range of accommodation. The nearest point at which an object can be seen distinctly, the letters of a printed page for example, is called the near-point of vision and measures the maximum power of accommodation.

Unfortunately our power of accommodating or focusing the eye becomes less and less as we grow older. In fact the power drops off very uniformly in proportion to the age, so that if one measures the near-point of vision in the eye of any individual he can thereby determine his age with considerable accuracy. We don't notice this defect at first, but somewhere in the forties in a normal eye it obtrudes itself upon our notice. We have to hold a book or a newspaper inconveniently far away to see the

letters clearly, so far away in fact that ordinary printing becomes indistinct on account of the small size of the retinal images. This perfectly normal defect is known as old-sightedness, or presbyopia, and usually somewhere in the forties it becomes necessary to help the eyes in all near work, such as reading, by wearing magnifying or convex glasses selected so as to give distinct vision at a comfortable reading distance. If the eyes are otherwise normal, that is do not suffer from astigmatism, or short-sightedness, or far-sightedness, the individual still sees distant objects perfectly without glasses. He needs to wear the glasses only for near work. In spite of the universality of old-sightedness it seems to come as a surprize to almost every one, and the individual usually comforts himself by calling attention to the fact, which is undoubtedly true, that he can see as well as ever for distant objects. Old-sightedness comes to the near-sighted and far-sighted as well as to the normal eye, but the effects upon vision and the nature of the glasses to be worn are different and can not be well explained without going into optical details.

The Iris

There is another very neat and effective mechanism in the eye which should be referred to and that is the device furnished by the iris. The iris is the colored membrane back of the cornea which gives the characteristic color to the eye. It is pierced by a central opening or aperture, the pupil, which looks black to us as we gaze at the eye from the front, because it opens into the dark interior of the eyeball. The iris has two minute muscles in it, one which, when acting, pulls the curtain apart, widens the pupil and lets more light into the eye; while the other has the reverse effect, pulls the curtain to and

thereby diminishes the size of the pupil. This beautiful mechanism acts wholly unconsciously in response to the light. When much light falls on the eye the pupil is narrowed, and while this lets in less light it greatly improves the focus of the image by letting the light through only at the center of the crystalline lens. It is the device known as diaphragming which all photographers use when they wish to get a sharp focus. In dim lights, on the contrary, the iris dilates, causing an enlargement of the pupil, as it is then advantageous to let in as much light as possible to see external objects at all whether perfectly focused or not. Both the contraction and dilatation of the iris, the narrowing and enlargement of the pupil, are effected by reflex acts.

It is an exceedingly smooth mechanism acting automatically in proportion to the amount of light falling on the eye. Instrument makers have imitated the mechanism by constructing what are called iris diaphragms, in microscopes for example, which can be opened and closed to let in more or less light, only in this case the adjustment must be made by the hand of the observer and not as in the eye by the action of the light itself. There are many other most interesting properties of the eyes, such as their ability to distinguish different colors, the muscular adjustment of the two eyes so as to give us single vision in spite of there being two retinal images, the ability with two eyes to perceive perspective or three dimensions of space, etc., for a description of which larger treatises must be consulted.

CHAPTER VII

THE REPRODUCTIVE ORGANS

The Power of Reproducing

THE POWER of reproducing itself has long been recognized as one of the most characteristic properties of living matter. In some of the lowest forms of life the process is simple. The little one-celled organism may multiply by merely dividing into two after it has grown to a certain size, but simple as such a process may appear it is not possible to explain fully the reasons for its occurrence. No doubt it is a physicochemical reaction, due to the mechanical tension developed at the surface of the organism as a result of growth, but the underlying changes that lead up to it can not be followed in detail. In most of the cells existing in our body multiplication, that is the division of the cell into two, becomes more complicated. The central nucleus undergoes a number of preparatory changes that lead to a very exact separation of its substance into two equal parts before the body of the cell follows suit.

It is possible to take some of the cells of the body and grow them in little glass vessels where the process may be watched under the microscope. Cultures of this kind have been kept going for many years by taking a few of the cells every day or so and transplanting them to a new medium. The rate of growth is astonishing. If it were possible to supply adequate food material and all the other necessary conditions, so that growth might go on unimpeded by accident or starvation, it is estimated that

a few cells in the course of several years might make a mass larger than this earth. Living matter in fact is irrepressible. The simpler forms are potentially immortal and would go on increasing to a dangerous extent were they not controlled by accident, disease, and starvation.

An eternal circulation of matter is going on between the living and the dead world. Out of the carbon dioxid of the air, and the water and inorganic salts of the soil the plant forms are constantly manufacturing organic products and living protoplasm, and out of the material furnished by the plants the animal organisms in turn construct their form of living substance, while steadily during life and in the disintegration following death the organic material is being converted back to carbon dioxid, water, and inorganic salts.

In the higher forms of life the cells of the various tissues exhibit the power of reproduction in the sense that they can multiply by cell-division, but, speaking generally, such cells can only produce others of the same kind. The property of building a new complex organism is restricted to the so-called reproductive cells. The course of evolution of the higher forms of both animals and plants has resulted in the development of two sexes, and the formation of a new individual begins by the union of one of the reproductive cells of a male organism with a reproductive cell of the female organism. This fusion of the spermatozoon of the male with the ovum of the female constitutes the act of fertilization, and from the fertilized ovum a new individual arises.

Methods of Reproduction

Many and varied are the devices of nature for bringing together the two sex cells. Sometimes, as in the case of plants, it is left more or less to chance,

the pollen of the male flower is borne by the wind or water or by insects to the pistil of the female flower; but in most of the animal forms there is a copulation of male and female, and by means of an intromittent organ of some kind the male cells are deposited within the body of the female so as to come into contact with the ova. To ensure the continuation of the species in such forms there has been developed a strong sex-instinct which drives animals into sexual union. It is a method of securing the perpetuation of the race that is more certain than giving the seed to the wind or tide, but some echo of the old device is seen in the fact that the male cells, the spermatozoa, are always produced in vast numbers. A single ejaculation contains millions of them altho only one is needed to fertilize the ovum, the balance eventually die. When the spermatic liquid is deposited at the mouth of the uterus it is a matter of chance whether or not any of the spermatozoa meet the tiny ovum, and the possibility of failure is eliminated by multiplying enormously the number of spermatozoa.

In the human female the reproductive life extends from puberty, at about the fifteenth year of age, to the menopause or change of life which is reached, as a rule, about the forty-fifth year. During this period an ovum is released from one or the other of the ovaries once every twenty-eight days. It is believed now that this act of ovulation, as it is called, occurs at about the middle of the menstrual period, that is, midway between two menstruations. The liberated ovum passes into one of the Fallopian tubes of the uterus and makes its way slowly down the tube toward the uterus. The passage takes perhaps three or four days. If sexual union has occurred about this time the spermatozoa, owing to their motility, make their way along the interior of the

uterus and into the tubes. If they meet with the ovum one of them unites with it and the act of fertilization is accomplished. If this does not occur the ovum degenerates soon after passing into the uterus. If the ovum is fertilized, then after reaching the uterus it becomes attached to or implanted in the mucous membrane and undergoes rapid growth. Where it is attached to the mucous membrane there is developed a special organ, the placenta, through which the growing embryo is nourished from the maternal blood. During this period of growth no further ovulation occurs, and after nine months the child comes to term, and changes occur which are not well understood, but which lead to contractions of the uterus and the birth of the child.

The changes that ensue after the union of the two reproductive cells present two main features which have long been objects of study by the biologist. In the first place there is the rapid growth and multiplication of the fertilized ovum. The unfertilized ovum, if left to itself, does not increase and multiply; but, after union with the spermatozoon, growth begins quite promptly and in course of time the single cell gives rise to the uncountable millions of cells of various kinds which constitute the animal organism. In some of the lower forms of life the stimulus communicated by the spermatozoon may be imitated by the use of artificial stimuli and the unfertilized ovum be started upon a period of growth similar to that following natural fertilization. But we are as yet ignorant of the exact way in which the spermatozoon acts in initiating this long-lasting outburst of activity. The rate of growth is at first extremely rapid. In human beings during the first month of intrauterine life the ovum increases more than ten thousand times in size, but after this the rate falls off very rapidly, so that at birth the

monthly increase is represented by a fraction, 0.45; that is to say, the gain in weight during a month is only forty-five one-hundredths of the weight at the beginning of the month. After birth growth continues, of course, up to adult life, when for a long period of years in man the size remains unchanged. Multiplication of cells takes place in some of the tissues but only sufficient to replace those that are lost.

Heredity

The second and most mysterious feature of reproduction is comprised under the term heredity. When the fertilized ovum starts to multiply it does not produce simply a mass of cells like itself. On the contrary the new cells quickly begin to differentiate in shape and function to form tissues and organs like those of the parents, and in the end there is produced an animal organism which in structure and size is practically a replica of its parents. The fertilized ovum of the whale produces a whale and that of the mouse a mouse. For want of a better term we speak of the fertilized ovum as possessing a form-building property which it owes to heredity. While this property ensures that each ovum shall develop an animal of its own kind, we know that heredity acts also to produce an individual diversity. Every child, while inheriting the general characteristics of the race, has distinctive features, both physical and mental, which characterize it and which it derives from its immediate ancestors. Barring perhaps the case of true twins, no two children are ever exactly alike. It is evident that the reproductive cells carry within themselves certain properties which guide the development of the offspring along a definite path. For many years biologists have employed every possible means to discover the details of struc-

ture and composition of the reproductive cells in the hope of throwing some light upon the mechanism of heredity. This work has gone far enough to show that there is a visible mechanism which is concerned in this phenomenon. It is found in the so-called chromosomes of the nucleus of the reproductive cells. To make clear what the chromosomes are and how they act in hereditary transmission it is necessary to refer briefly to the structure of the ovum and spermatozoon and the changes that occur in them before and during fertilization.

The ovum is a spherical cell of unusually large size having a diameter of about one one-hundredth of an inch. It has in its interior a spherical body, the nucleus, and in this nucleus there is a material known as chromatin, because of the readiness with which it stains with dyes. The chromatin is arranged usually to form a network; but when the cell is preparing to divide, the network breaks up and the chromatin is gathered into a number of separate bars or rods which are the chromosomes. The cells of each species, including the ova, have a characteristic number of chromosomes. In man the number is forty-eight. When a cell divides, each chromosome is first split longitudinally into two, and in the division that follows one-half of each chromosome goes to each cell, so that every cell possesses the characteristic number. In its early stages the ovum follows this procedure when it divides, but later when it matures and is ready for fertilization it undergoes a division of a different sort in which the chromosomes do not split, but half of them go to one cell and half to the other, the result being that the mature ovum contains only 24 chromosomes.

The spermatozoon in mature form is a very minute cell of peculiar shape. It has a head about 1/5000 of an inch in diameter and a tail about 1/500 of an

inch in length. The tail is motile and by its contractions from side to side can move the cell through a liquid medium. The head of the spermatozoon is the nucleus and contains the chromatin material in the form of the chromosomes. In its young form while still a spherical cell without a tail piece, the spermatozoon contains 47 chromosomes, but as in the case of the ovum they are reduced in the process of maturation so that the fully formed spermatozoon ready for fertilization contains only 24 or 23 chromosomes. When the spermatozoon and ovum come together, the head or nucleus of the former enters the ovum, the tail is left outside. The spermatozoal nucleus, with its 24 or 23 chromosomes, unites with the ovarian nucleus, containing 24 chromosomes, so that in the fertilized ovum the chromosomes are restored to their normal number of 48 or 47, half of which have a maternal and half a paternal origin.

The chromosomes are considered to be the bearers of the hereditary characteristics, and it will be seen that by the arrangement described the fertilized ovum that is to give rise to a new individual obtains half of its inheritance from each parent. But as bearers of hereditary characters the chromosomes are not all alike so that what the child gets from the father and what from the mother depends upon the parceling out or separation that takes place in both ovum and spermatozoon during the so-called reduction division in the process of maturation.

The greatest contribution to our knowledge of the mechanism of heredity was made many years ago (1866) by an Austrian monk named Gregor Mendel. For a long time his work was disregarded by scientific men, but in recent years its importance has been fully recognized. He conducted breeding experiments mainly on the plants in his gardens, crossing them in various ways and making observations on the

inheritance of visible characters, such as color, form, and structure. He discovered that some characters can be treated as units. They may be shifted about by crossing in different ways, and their occurrence in the offspring of any given mating may be predicted with certainty in accordance with certain formulas. If, for example, a plant with a red flower is crossed with another plant of the same species having a white flower then in the offspring there will be a mixture of the two characters, and since the red color is dominant, all the flowers of this first generation will be red. But if these hybrid flowers are self-fertilized or crossed with one another it will be found that the two characters have again separated. In the offspring of the second generation there will always be three with red flowers to one with white flowers.

The hypothesis that is proposed to explain this result assumes that in the reproductive cells of the first generation the characters are sorted out in equal numbers, that is, half of the pollen grains have the red inheritance and half the white, and the same for the ova. When now these are brought together in numbers, four combinations may take place. First, a pollen grain with the red inheritance, or for convenience we may say a red pollen, unites with a red ovum, the result being a plant with a red flower. Second, a white pollen unites with a white ovum, the result being a plant with a white flower. Third, a red pollen unites with a white ovum and fourth a white pollen with a red ovum. In the last two cases we have hybrids and since the red predominates the resulting plants have red flowers, giving, as was said, a total of three plants with red flowers to one with white. If these plants are now taken separately and self-fertilized, the one with white flowers gives offspring that have only white flowers. One of those

with red flowers, by hypothesis the one in which a red pollen had fertilized a red ovum, gives offspring that have only red flowers, while the two other red flowers, being hybrids and possessing both characteristics, give a progeny in which there are again three plants with red flowers to one with white. One can readily see that experiments of this kind may be modified in various ways with reference to any two contrasting characters, such as redness and whiteness or tallness and shortness, and in many most interesting experiments the results to be expected on the above hypothesis of the equal separation of the characters in the germ cells have been obtained.

As a result of the great amount of work that has been done along these lines it is now believed that inheritable characters of this kind are represented in the germ cells by definite substances or particles to which is given the name of genes. It is further believed that these genes are contained in the chromosomes, arranged perhaps in a linear series, one after another along the length of the chromosome, and the part taken by each chromosome in hereditary transmission will depend upon the character of the genes contained in it. On such an hypothesis we can form some conception of the mechanism by which the constant racial characteristics are transmitted, along with those minor differences or diversities which characterize each individual. The specific or racial characters are transmitted through genes which are alike in both sexes and which control the shape and size and general structure of the animal, but minor or individual characters, such as the color of the eyes, are represented also by genes or groups of genes which differ in their possibilities and in their distribution among the chromosomes. If one parent has blue eyes and the other black eyes, then

assuming that there is a sufficiently numerous progeny, the color of the eyes in the children will be distributed in accordance with the Mendelian laws. Characters of this kind which act as separate units and may be made to appear or disappear according to the nature of the mating are spoken of as Mendelian characters, and the sort of inheritance that can be predicted from the hypothesis given above is frequently referred to as Mendelian inheritance.

It is easy to see that if the genes are numerous, as they must be, the possible combinations that may be made are infinite in variety. The inheritance of any one individual is determined in a general way when the particular spermatozoon and ovum come together to make the fertilized ovum from which he develops. But only in a general way, since experimental work indicates that the extent and character of the development may be modified in many particulars by the character of the environment to which the fertilized ovum is exposed during its growth. As a recent writer (Jennings) expresses it, "We know now that many characters that are inherited need not be realized, if the environment is properly constituted, and that many inherited characters will not be realized unless the environment is properly constituted. . . . What an organism inherits is the power to produce certain characteristics under certain conditions, others under other conditions." Nature and nurture, heredity and environment both play important rôles in the final molding of the individual's body and mind.

We have no idea of the structure or size of the genes. It is assumed that they are material particles, but whether they are of molecular dimensions or larger is one of the problems for the future. Nor can we form any definite conception of the way in

which they influence and guide the processes of development of the fertilized ovum. There must be something very definite in their structure to account for that potential difference which finds expression in the final separation of the organism into organs and tissues varying so greatly in form and function. But leaving aside these troublesome details the general features of the theory now held enable us to comprehend how these ultimate units may be combined during development in a great number of ways and thus lead to an endless diversity in the individuals of a species. By our system of marriages the genes that constitute the germinal protoplasm of different human stocks are constantly being brought together in new combinations. With this method of breeding, pure stocks or pure lines can not be established, but rather an immense variety.

The physical and mental characteristics of children depend upon the genes derived directly from their parents, but in each of these parents the genes have come down through a long line of ancestors, so that the combinations that take place in any one generation may revive the structure and qualities of the immediate parents or of some of the many forbears. Dominant physical characteristics may come from one parent and mental traits from another, or there may be a "throwback" to some more remote ancestor. Among the lower animals we can intensify and perpetuate special traits of a physical or functional character by selective breeding. No doubt we could do the same thing in man if we could control his mating in the same arbitrary fashion. At present such a procedure is neither feasible nor desirable since we lack the requisite knowledge to apply it properly in any extensive way, but there can be no question that mankind will find a method of using

the knowledge we now have or will have in the future to improve the human stock in some particulars. Hopelessly bad strains might be minimized, at least, without doing violence to our sense of humanity.